Unclassified

THE BONNEY-FLOYD COMPANY

COLUMBUS, OHIO

FINAL REPORT

PRODUCTION OF HIGH STRENGTH CAST STEEL SUSPENSION ARMS FOR TRACKED VEHICLES

By

C. D. ROBINSON

April 1962

Contract DA-33-019-ORD-3398
performed under the Technical Supervision of
Research and Engineering Directorate
U. S. Army Tank-Automotive Center
OMS Code No. 5510. 12. 26800.02

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Authorization: Cleveland Ordnance District Contract DA-33-019-ORD-3398

TITLE

PRODUCTION OF HIGH STRENGTH CAST STEEL SUSPENSION ARMS FOR (T95 MEDIUM TANK) TRACKED VEHICLES

ABSTRACT

High strength steel castings are produced in the production foundry by following a manufacturing procedure which relates each production operation to the function of the casting being produced. This manufacturing procedure is based on the fact that slight modifications of normal production techniques can produce useful steel castings at the 170,000 psi minimum yield strength level if proper control of processing operations is exercised. Design information is used to develop a foundry practice which promotes solidification of homogeneous metal in critical areas. The additional manufacturing operations, molding, melting, heat treating and inspection, are all used to obtain and retain the properties designed into the high-strength steel casting. Using these principles, mechanical properties of 4340 high-strength steel castings have been obtained as follows:

UT.S (psi)	.1% Y.S. (psi)	.2% Y.S. (psi)	Elong. %	R.A. %	Impact * (-)40 ft. lbs.
205,000	179,500	181,500	9.0	21.6	12.6

APPROVED:

J.L.V. BONNEY, JR.
President
The Bonney-Floyd Company

CLAUDE D. ROBINSON
Metallurgist

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FINAL REPORT

TITLE

PRODUCTION OF HIGH STRENGTH CAST STEEL SUSPENSION ARMS FOR TRACKED VEHICLES

I. OBJECT

To develop procedures and produce high strength steel castings in the production foundry.

II. SUMMARY

Design information was used to develop manufacturing procedures which related each production operation to the function of the cast high strength steel suspension arm. The individual operations, pattern making, rigging, molding, melting, riser removal, heat treatment, inspection and machining were then utilized in the production of suspension arm castings.

Both production castings and test coupons were destructively tested to qualify respectively the processing procedures and each melt produced during this investigation.

III. INTRODUCTION

The desire to produce lightweight equipment through utilization of high strength cast steels has resulted in the publication of a great deal of information on the production and processing of these steels. Even a brief inspection of this information shows that production and processing techniques suitable for low strength cast steels (below 150,000 psi tensile strength) are not recommended for these higher strength steels. In many cases, processing operations presented in the literature are foreign to methods in use in production foundries.

It is realized that procedures developed in the laboratory are intended to optimize the mechanical properties of the castings being investigated. However, some of the processing operations reported in the literature appear to be marginal from the standpoint of providing any real contribution to optimum mechanical properties. It is often these same processing operations which are both expensive and undesirable in the foundry.

This report outlines a manufacturing procedure capable of producing high strength steel castings. Wherever possible, the processing operations used in the development and production stages of this program simulate normal production practices for those foundries producing high quality castings.

The results of mechanical testing submitted for examination are in strength range between 200,000 and 250,000 psi tensile strength, and represent various size test blocks and actual production castings.

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IV. PHILOSOPHY OF MANUFACTURE

A. DESIGN

The production of useful high strength steel castings must involve a series of adjustments and compromises. The first series of adjustments should take place at the design stage. After the function and geometry of the part have been determined, castability should be improved by avoiding sharp changes in section and by providing generous fillets at all section junctions. In addition to these "standard" features of casting design, it is very desirable to provide the foundry with data obtained from stress analysis calculations or measurements. Once the stress distribution and magnitude is made known to the foundry, proper steps can be taken to insure optimum properties in the high stress areas. The designer must also realize that nearly all castings produced by conventional foundry techniques will show a decrease in both impact and ductility in going from the cast surface to the center of a given section.[1] Techniques for obtaining uniform properties throughout cast sections will be detailed later in this report.

Realizing the limitations of conventional casting techniques will often enable the designer to adjust his design so that the optimum properties can be developed in those areas where they are required.

B. ESTABLISHMENT OF FOUNDRY PRACTICE

Equally as important as design, and perhaps the most important factor of all, is the proper selection of foundry practice. Work started in the development portion of this program, and reported partially in Progress Report No. 1, showed the desirable effect of controlled solidification on mechanical properties. Figure 1 (Controlled Solidification Test Casting) gives the location of tensile specimens removed from one test casting. A variety of molding materials were used and solidification was initiated at the cast surface adjacent to specimen D.

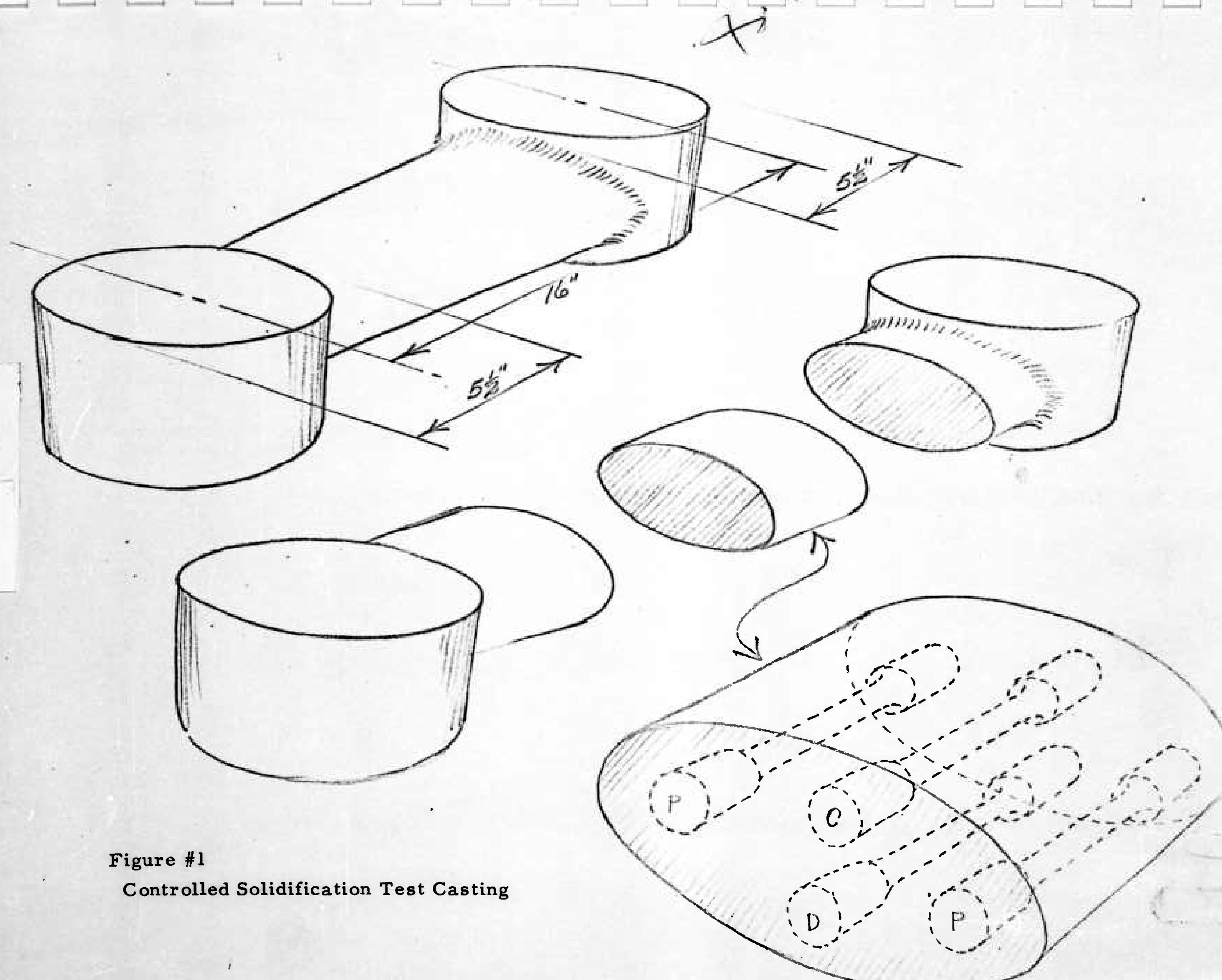

Figure #1
Controlled Solidification Test Casting

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The method of molding also caused solidification to terminate in the area of specimen C. TABLE I, lists the mechanical properties for this casting. All specimens received the same processing operations.

TABLE I

SPECIMEN * Heat 2-5454	0.1%-Y.S. PSI	TS PSI	ELONG. %	R.A. %	0.1%-Y.S. / TS
C	211,000	236,500	2.0	4.8	.89
D	212,000	248,300	7.5	17.7	.85
P	215,000	250,000	5.0	8.9	.86
P	215,000	249,000	5.5	8.9	.87

*All specimens water quenched from 1600°F.
Tempered @ 500°F.

The data listed in Table I show that superior mechanical properties were obtained from those sections where solidification was associated with steep thermal gradients. Figure 2 is a photomacrograph of the etched surface of the section removed for mechanical testing. The poorly defined fine columnar structure present in the lower portion of the section indicates that this area is relatively homogeneous, both chemically and physically. The upper portion of this same section, however, appears to have a heterogeneous nature. The effect of chemical and physical homogeneity on mechanical properties is given in Table I. The nature of chemical and physical heterogeneity and their adverse effects on cast high strength steel has been reported by many investigators.[2-3]

Since present nondestructive tests cannot detect the presence of undesirable heterogeneity on the micro scale, it is imperative that a foundry practice be developed which is capable of providing the required degree of micro-soundness.

If the foundry is supplied with the necessary design information, it is possible to formulate a foundry practice which should provide optimum mechanical

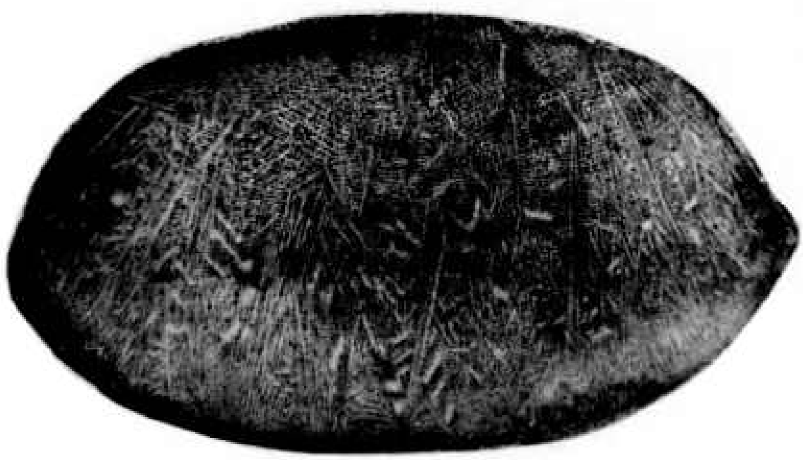

Figure -2: Macroetched Cross Section of Test Casting Shown in figure -1. Etched 20 minutes @ 170°F in 50 HCl-50 H_2O solution. (full size)

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properties in required areas. The establishment of a suitable foundry practice is subject to several intangible variables. At this time these variables can only be resolved by destructive testing of castings produced by following the proposed practice. It is probable that experience will provide a semi-quantitative method of predicting micro-soundness, as has been the case for macro-soundness.

C. MELTING PRACTICE

The present philosophy regarding melting practice favors the basic arc-furnace as the best method of producing high strength low alloy steel. Optimum mechanical properties can be obtained, only if every practical known method is used to reduce detrimental residual elements to the lowest possible level. When the induction furnace is used for remelting, refining of the steel is impractical. Since induction refining is impractical, the most desirable way to utilize induction melting is by remelting a master alloy produced in the arc-furnace.

During this investigation castings were produced using both arc and induction melting. Castings which were produced from induction remelt of an arc-furnace master alloy had identical mechanical properties with the castings produced in that arc-furnace heat. The assumption must follow that, at the strength level under investigation, (170,000 psi yield strength) an induction remelt has no detrimental effect on the measured mechanical properties. It was also observed that when the induction furnace was used as the only melting operation, i.e., melting a virgin charge of Armco iron and ferroalloys, mechanical properties were inferior to those for both the arc-induction and arc practice.

D. HEAT TREATMENT

The heat treatment is designed to serve two purposes. Initial heating and cooling operations should aid in processing of the castings. Secondary, or final, heat treatment must maximize the development of the martensitic low temperature

transformation product.

1. Initial heat treatment

An adequate preliminary heat treatment which will prepare castings for riser removal and contour work is a 1750°F normalize, followed by a 1200°F tempering operation. At the 170,000 psi yield strength level, high temperature homogenization is not used, since its effect on final properties is marginal. Also, proper homogenization is expensive and requires heat treating equipment not common in most foundries. At strength levels in excess of 200,000 psi, high temperature heat treatments, properly used, may provide worthwhile property improvement.

2. Final heat treatment

The tempered martensite structure is known to provide optimum mechanical properties in high strength low alloy steels. The final heat treatment is then designed to produce the greatest possible amount of tempered martensite. The austenitizing temperature is approximately 150 to 250°F above the A_{r3} prior to quenching.

The quenching operation is a critical step in final heat treatment and should be just fast enough to promote martensite formation in the cast sections of interest. Higher quenching rates than required to form martensite promote the retention of metastable austenite. When heavy cast sections are involved severe quenching is required to promote martensite formation throughout the section. When severe quenching is necessary, retained austenite is eliminated by multiple tempering. If controlled solidification has been used, improved chemical homogeneity, on the micro scale, will minimize retention of austenite.

Selecting the "optimum" tempering temperature for high strength steel castings requires a definite compromise. In general, if optimum impact properties are to be obtained, the tempering temperature must be greater than 1100°F. For the case of a 4340 type alloy, tempering above 1100°F develops tensile properties

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at the 150,000-160,000 psi range. If the 200,000 psi tensile strength level is to be obtained, tempering temperatures in the 900°F range are necessary. The general observation has been that tempering in the 600-1100°F range causes a disproportionate decrease in impact strength for the increase in tensile strength. If tempering temperatures below 600°F are used, as opposed to the 600-1100°F range, impact strength is often increased while maintaining the higher tensile strength. Adjustment of carbon content so that the desired strength level can be obtained without tempering in the 600-1100°F range is suggested as one method of improving impact strength.

X

E. NONDESTRUCTIVE TESTING

The effective use of nondestructive testing requires detailed knowledge of the intended function of any particular casting. The type of loading, as well as the direction, location, and magnitude of stresses, aids in the design of adequate inspection techniques.

1. Radiography

Radiographic inspection should be used to insure that proposed foundry practice can provide macro-soundness. It is also a valuable tool in the inspection of critical areas for random type discontinuities - such as inclusions.

2. Magnetic Particle

The primary inspection method available for establishing the integrity of high strength steel castings is the magnetic particle technique. It offers the best method for detecting surface discontinuities. For most casting configurations, the continuous method using dry powder, half-wave rectified power supply, and prods offers the best inspection. Experienced inspectors using this method will be able to detect both surface and slightly subsurface discontinuities.

It is in magnetic particle inspection where design information is essential to establish "prod patterns" and current settings that are capable of detecting all potential stress raisers.

3. Liquid Penetrant

Penetrant inspection methods are often used in conjunction with magnetic particle inspection of critical areas. If the casting geometry is such that proper magnetic particle testing is impossible, then liquid penetrant inspection offers a suitable alternate method. In most cases magnetic particle inspection is preferred to liquid penetrant inspection, since it detects both surface and subsurface discontinuities.

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V. PROCEDURE

A. TECHNICAL SCOPE

The production practices and philosophy of manufacture developed during the preliminary stages of this program were applied to a useful casting geometry. The casting configuration developed as a high strength steel casting is shown in Figure 3. In this case the casting, front and rear suspension arms for the T95 tracked vehicle, was produced at the 170,000 psi minimum yield strength level.

B. DESIGN CONSIDERATIONS

The suspension arm shown in Figure 3 has been designed by Ordnance Tank Automotive Command in two configurations, either a hollow or a solid section connecting the hubs. In both cases the maximum stress is developed at the outer surface of the arm. The metal near the center of the section experiences only low level stresses.

Design information shows that alternate impact loading in tension and compression demands that no stress raisers be allowed to remain in the arm section or at the hub-arm junction. Since impact loading is standard, it was also decided that a 0.394" square V-notch Charpy specimen should be able to absorb a minimum of 10 ft. lb. energy during fracture at minus 40°F.

Since maximum stress is developed near the surface of the arm section, OTAC and Bonney-Floyd agreed to remove test specimens from the mid-wall position of castings presented for destructive testing.

C. FOUNDRY PRACTICE

Design information indicates that optimum properties for these castings are required from the surface of the arm to a depth of not less than 1/2 inch. Since design calculations are based on 170,000 psi yield strength, the foundry practice is intended to control solidification so that reasonable impact and ductility are

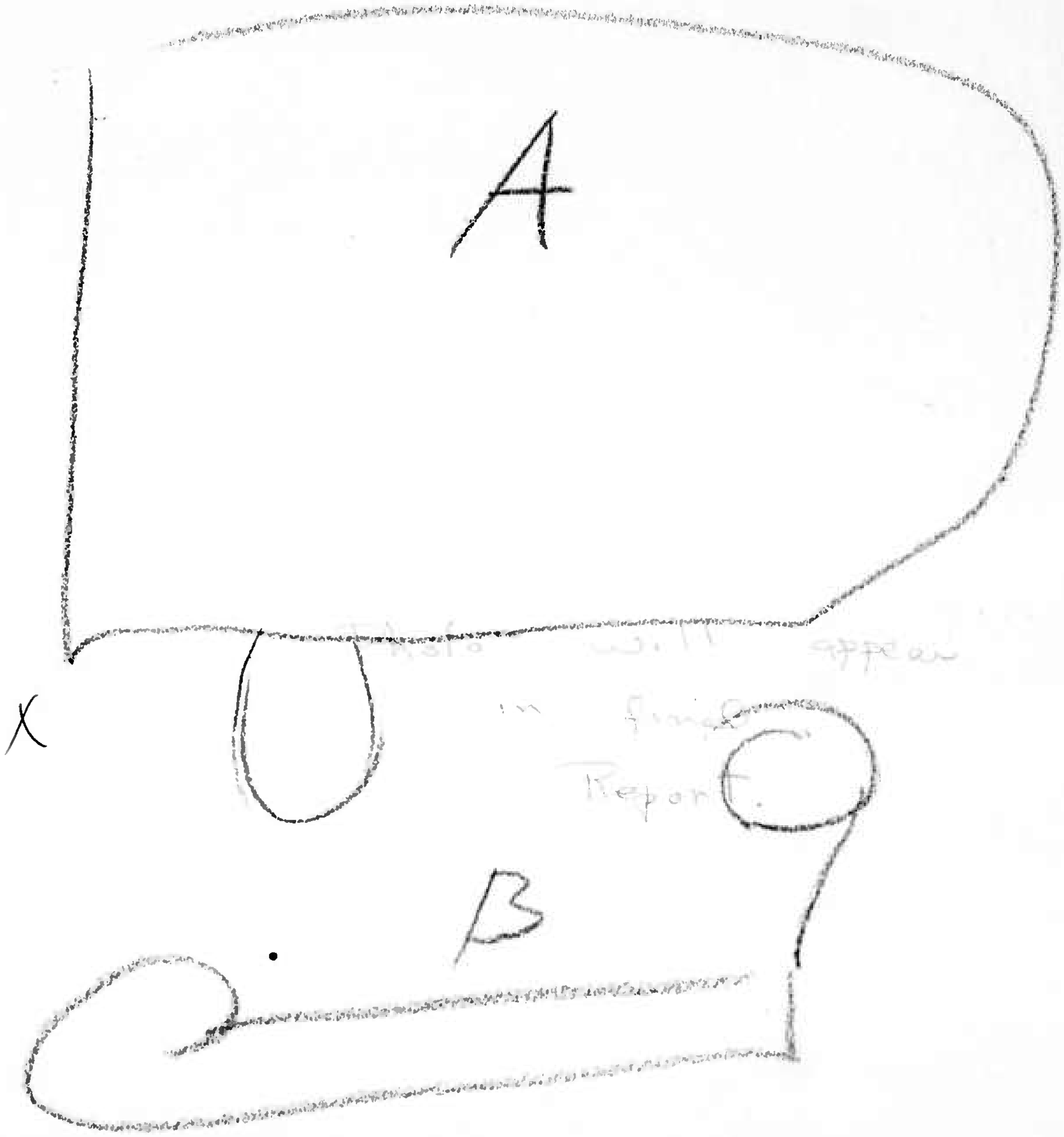

Figure 3: Suspension Arm Castings Produced in This Investigation

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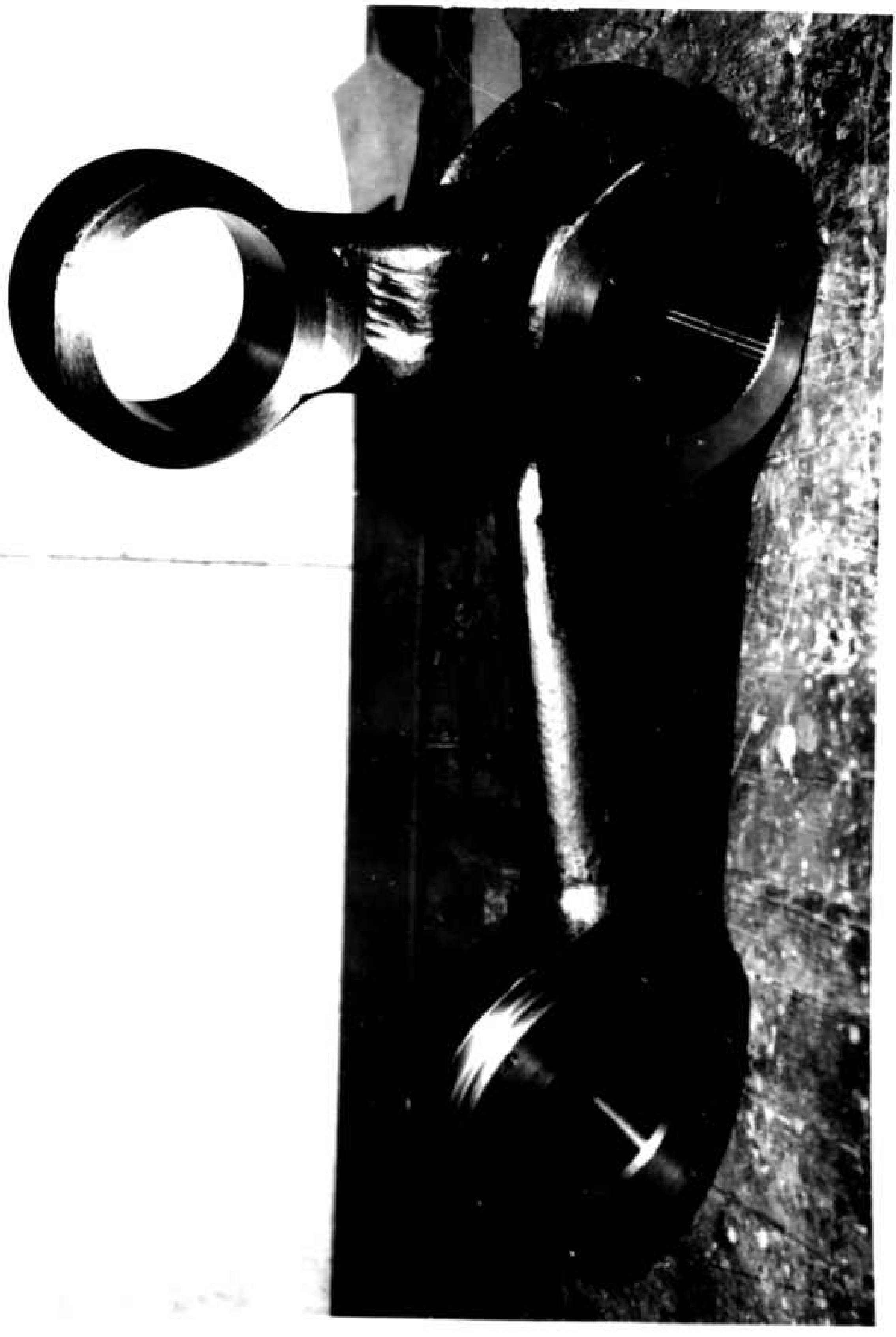

provided in the highly stressed areas when the casting is heat treated to this strength level.

Two methods were considered for molding the solid suspension arms which would provide the required degree of chemical and mechanical homogeneity in the critical areas. The first method requires that unidirectional solidification[2] be established in the arm section between hubs. It was proposed that the drag mold be produced in a molding material of high chilling potential (such as zircon). The cope was to be molded in exothermic material promoting unidirectional solidification from the drag toward the cope side. Figure 2 shows that such an arrangement only displaces the heterogeneous area closer to the cope surface. This method was then modified by adding enough additional stock and exothermic material so that the heterogeneous area was displaced outside of the desired casting configuration. Figure 4 is a photomacrograph of the etched cross section of arms produced by this method. The unsound metal in the padded area is then removed leaving only homogeneous metal in the casting. X

The castings submitted for field testing were produced by the second method which is less elaborate and considerably less expensive. In this case design information was used to produce a solidification pattern which causes solidification of homogeneous metal where it is required - near the surface of the arm. Cope and drag molds were produced using zircon sand facing to a depth of 1 to $1\frac{1}{2}$ inches from the mold metal interface. Steel chills were then rammed in this layer of zircon sand as an added heat sink. The zircon face was then backed up with a "standard" dry sand mixture. Brackets, to prevent cracking, were cut in the mold in locations where there was a sharp change in section. Risers were located over the hubs and side arm as shown in Figure 5. The castings were bottom gated through ceramic tile. Ceramic tile was used as a runner system to prevent mold erosion during pouring.

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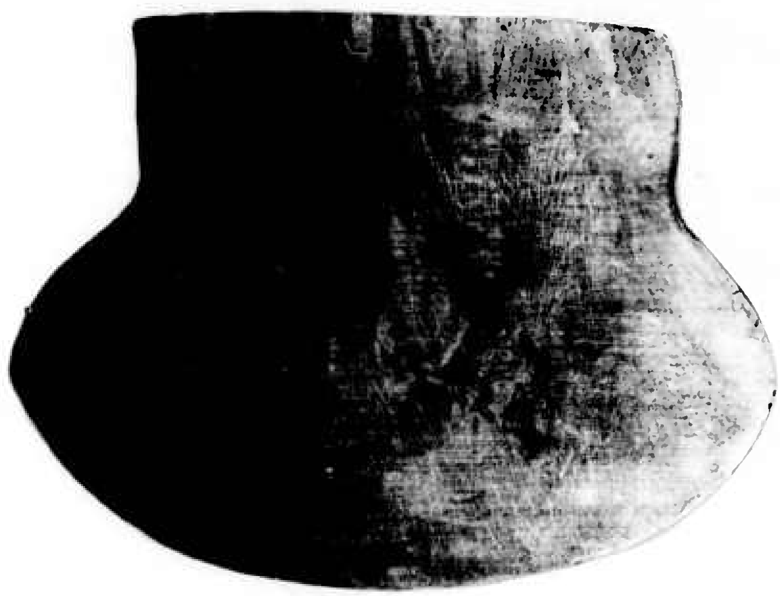

Figure 4: Macroetched Cross Section of Modified Test Casting (full size)

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Figure 5: Basic Pattern and Rigging Used To Produce Suspension Arm Castings

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D. MELTING PRACTICE

Any melting practice which is used to produce low alloy steel for high strength steel castings must satisfy several requirements.

1. Selected raw materials are used for the furnace charge. Purchased scrap and foundry returns are suitable for the arc-furnace charge provided they do not contain unwanted residual elements which cannot be removed by the refining operations. Pure ferroalloys are used for alloy additions and they must be low in undesirable residual elements. The charge for induction furnace melting consists of a master alloy produced in the arc furnace under optimum refining conditions.[4]
2. Alloying and deoxidation are performed in such a manner that nonmetallic inclusions are held to an absolute minimum.
3. Tapping temperature is adjusted to the optimum range for the cast sections being produced.
4. Ladle refractories are inert to the metal being poured.

Initial castings produced in this program were induction melted using a charge of Armco iron and pure ferroalloys. While these castings had respectable tensile properties, they had low impact strength. For this reason an improved melting practice was designed.

The modified practice consisted of producing a master alloy in the basic lined arc-furnace. The charge was refined using a double slag practice which reduced the sulphur and phosphorus below 0.007%. The heat was then alloyed and completely deoxidized in the furnace. This master alloy was then tapped into a preheated bottom pour ladle. Both pigs for induction melting and suspension arm castings were poured from this heat.

The remaining castings poured in this program were induction melted using the master alloy produced in the arc-furnace as melting stock. For these heats, small alloy additions and deoxidizers were added in the ladle.

E. PROCESSING OF ROUGH CASTINGS

After pouring, all castings were allowed to cool in the molds to at least 600°F. before shakeout. Shot blasting was then used to remove all scale and adhering sand.

1. Riser removal

The "green" castings were normalized at 1750°F for five hours and tempered at 1200°F. Gates and risers were removed on cooling from the tempering operation. Since the risers were removed with an oxygen-acetylene torch, the castings were not allowed to cool below 600°F while burning. After riser removal the castings were stress-relieved at 600°F prior to rough grinding the riser stubs. Brackets used to prevent cracking during the casting operation were then removed and the castings were blasted to remove all foreign material.

2. Initial inspection

After the above processing operations were completed, all castings were inspected visually and by the magnetic particle test. All discontinuities revealed by initial inspection were investigated and removed by grinding. Any discontinuities which required metal removal below the final dimension of the casting were repaired by welding.

X

3. Repair welding

The location and extent of all areas requiring repair welding are permanently recorded prior to welding. The location of all welds on the castings submitted for field testing are shown in Figure 6 through 9. The welding procedure used for repair welding was:

Figure 7: Location of Welded Areas
(DTA 59826, Ser. #13)

Figure 7: Location of Welded Areas
(DTA 59826, Ser. #13)

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Figure 6: Location of Welded Areas
(DTA 59826, Ser. #5)

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Figure 6: Location of Welded Areas
(DTA 59826, Ser. #5)

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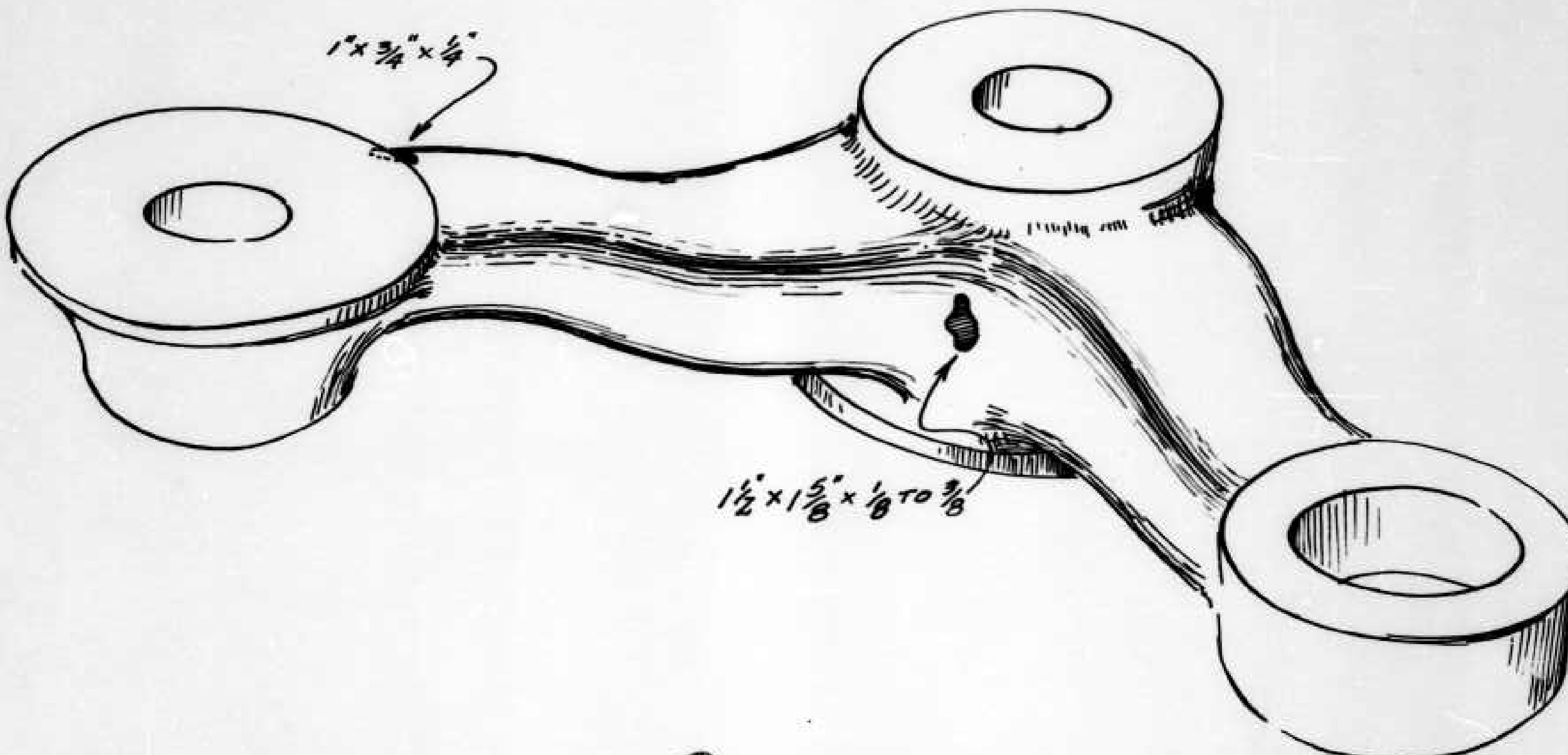

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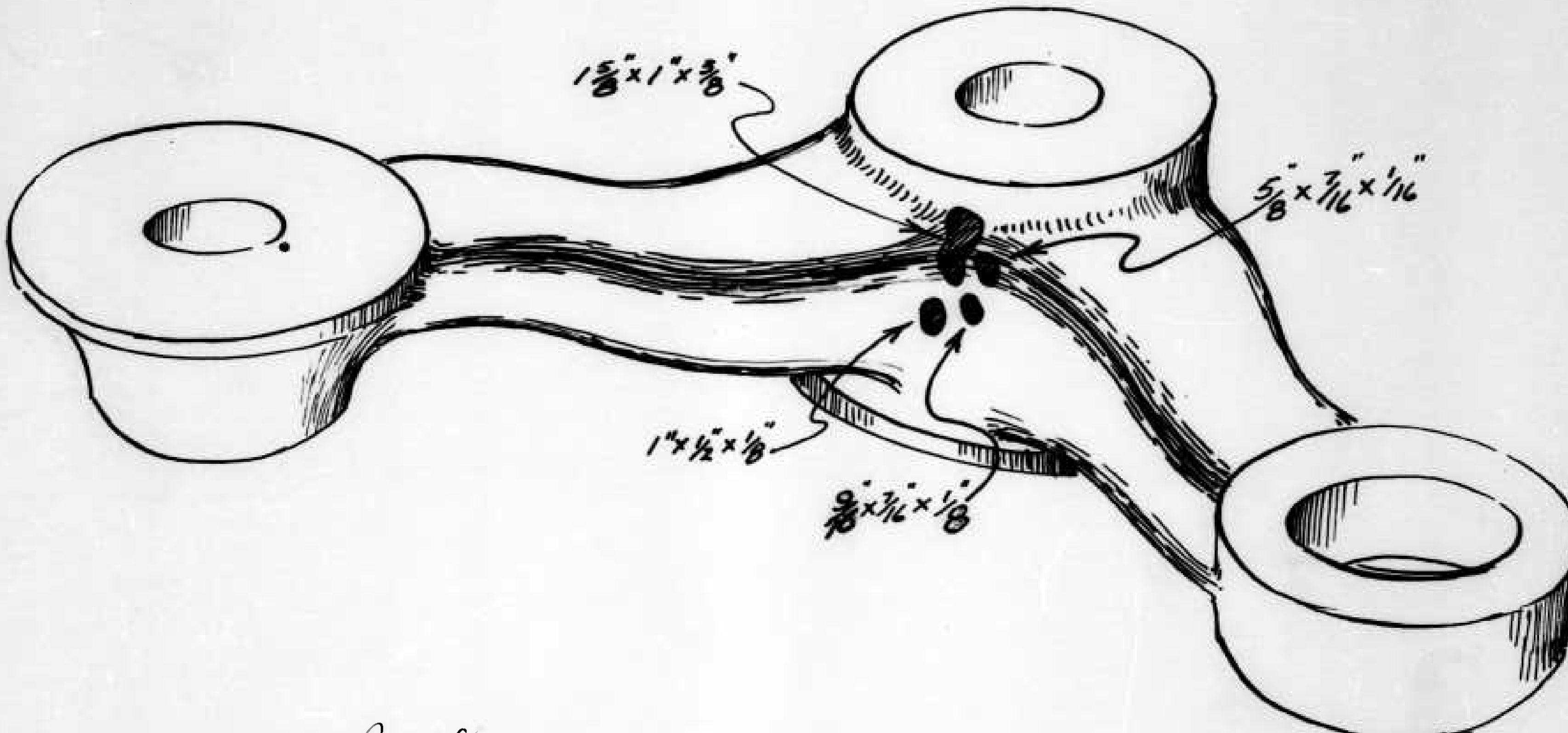

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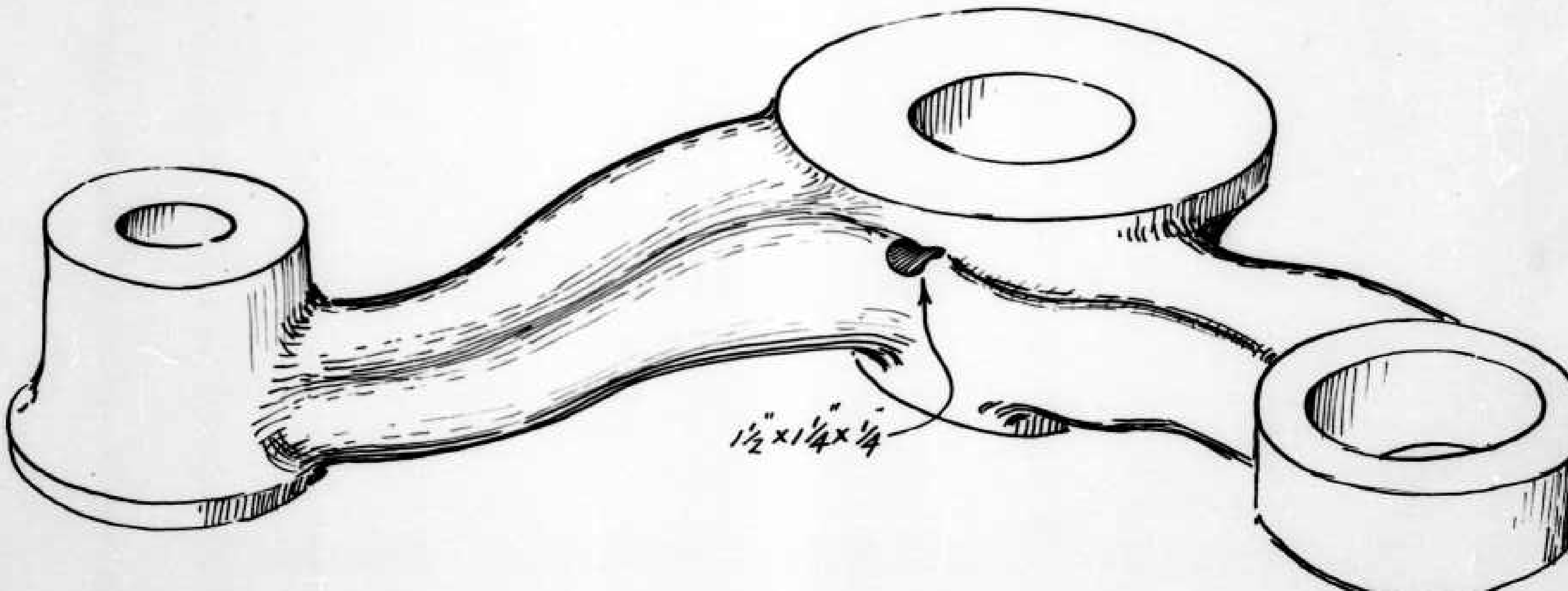

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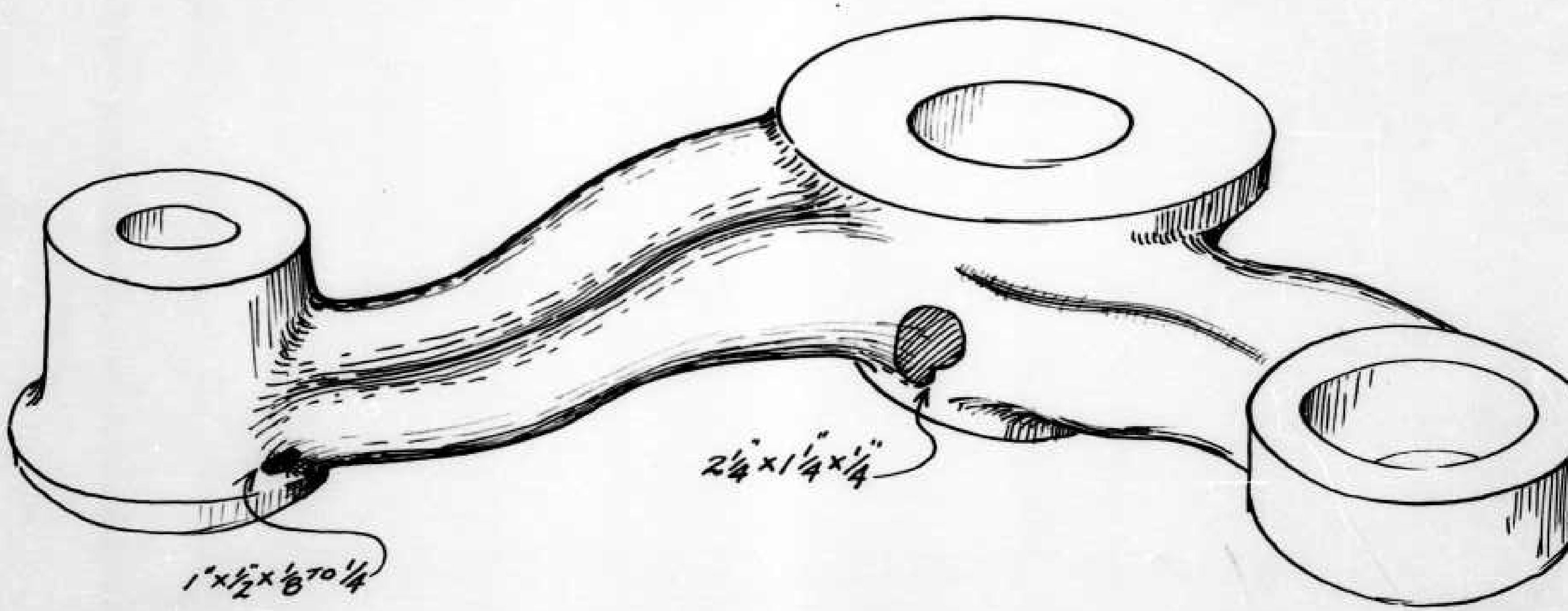

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Figure 8: Location of Welded Areas
(DTA 59827, Ser. #10)

Figure 8: Location of Welded Areas
(DTA 59827, Ser. #10)

Figure 9: Location of Welded Areas
(DTA 59827, Ser. #11)

Figure 9: Location of Welded Areas
(DTA 59827, Ser. #11)

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a. Filler Metal. Harnischfeger type P and H-4340, (MIL-E-8697) heat treatable electrode.

C - 0.35
Mn - 0.94
Si - 0.70
Cr - 0.80
Ni - 1.90
Mo - 0.40

b. Process. All welding was performed using the manual metal arc process.

c. Electrical Characteristics. The current used was direct current, reverse polarity, i.e., the base metal was connected to the negative side of the line.

d. Position. All welding was done in the flat position.

e. Preparation of Base Metal. All indications were removed to sound metal, as confirmed by both liquid penetrant and magnetic particle inspection, prior to welding. The method of defect removal was by grinding.

X

f. Cleaning of Welds. All slag and spatter were completely removed prior to making the next successive weld bead.

g. Appearance of Welds. Each weld bead was smooth in appearance and spatter-free. Undercutting of side walls was not allowed, and any undercut was removed by grinding before proceeding with the welding.

h. Preheat. Castings which required welding were thoroughly soaked to a temperature of 450°F. before welding. This temperature was maintained during the entire welding cycle. Upon completion of welding the casting was returned to a 450°F. oven to await post-heat treatment.

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i. Post-heat Treatment. The post-heat treatment was the final heat treatment, since all welding was performed in the normalized and tempered condition.

j. Inspection. After heat treatment welded areas were inspected by the magnetic particle method.

Welds made using the above procedure were checked for hardness and found to be in the same hardness range (40 RC) as the base metal. Although no mechanical tests were performed on welds made during this investigation, it has been demonstrated that this electrode deposits weld metal capable of being heat treated at 250,000 psi yield strength while maintaining Charpy "V" impact strength greater than 10 ft. lbs. at -40°F.

F. FINAL HEAT TREATMENT

After initial inspection, and repair welding when required, all castings received the final heat treatment. The procedure used was:

a. Austenitize at 1600°F for four (4) hours. (gas fired furnace).

b. Water quench for one (1) minute.

c. Air cool for thirty (30) seconds.

d. Water quench to 200°F.

e. Equalize at room temperature for two (2) hours.

f. Temper at 900°F for four (4) hours.

g. Air cool from the tempering operation.

h. Shot blast - decarburization was slight

G. FINAL INSPECTION

The final inspection consisted of radiography and magnetic particle inspection. The purpose of radiography was to establish the location of random type discontinuities, such as inclusions. Magnetic particle inspection was

performed with great care, since it is the best method available for the detection of surface imperfections which could act as stress raisers during service.

H. MECHANICAL TESTING

Castings produced by the various melting practices and processing procedures outlined above were sectioned and mechanically tested. A finned test casting (Figure 10) was also tested to establish the properties of those heats containing castings submitted for field testing.

Tensile properties were obtained from .505" diameter threaded tensile specimens and impact properties were obtained from .394" square "V" notch Charpy bars. These test specimens were removed from heat treated suspension arm castings, mid wall position, center arm. Where finned test castings were tested, the properties represent the "fin" section. The chemical composition and mechanical properties of castings produced during this investigation are provided in Table II and III, respectively.

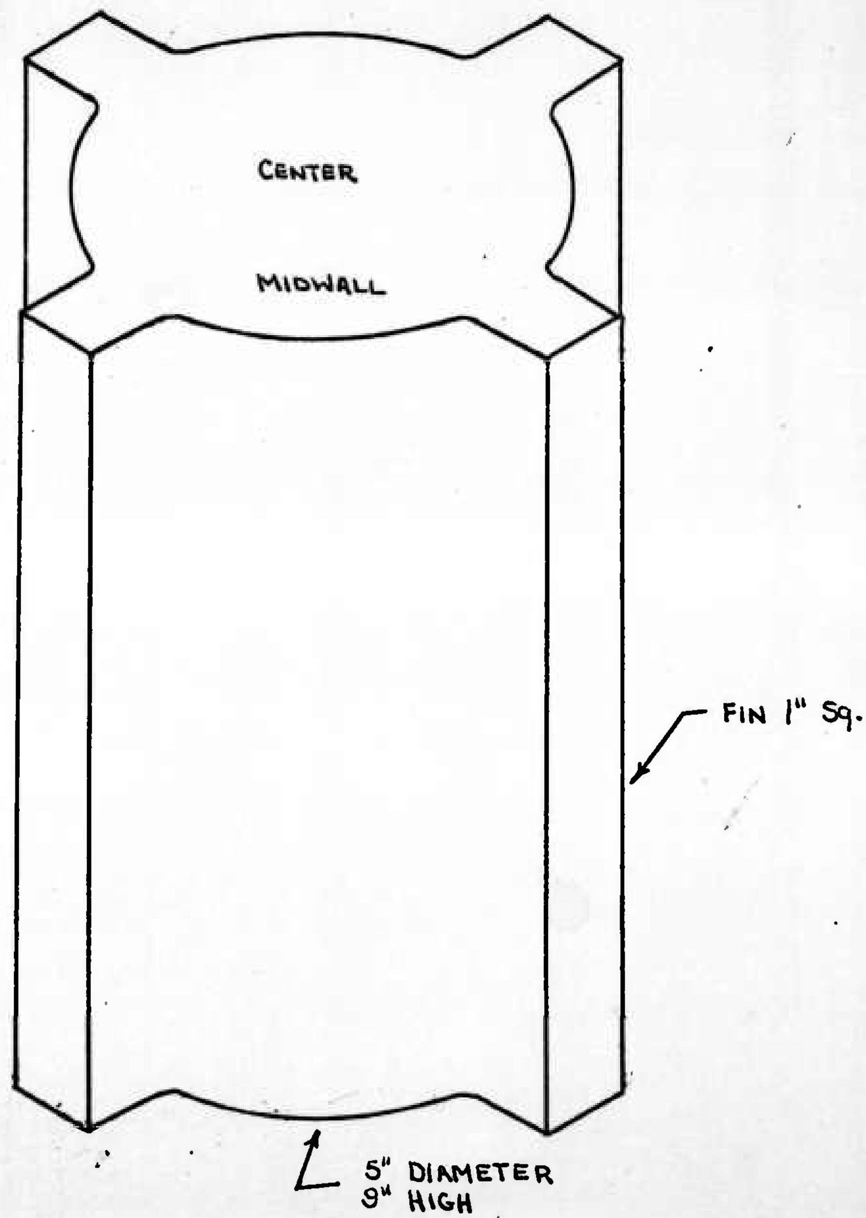

Figure 10: Finned Test Casting

TABLE II

CHEMICAL COMPOSITION OF ALLOYS PRODUCED IN THIS INVESTIGATION

HEAT NUMBER	MELTING PRACTICE *	%C	%Mn	%Si	%S	%P	%Ni	%Cr	%Mo	%V
2-5454	Acid-Arc	.30	1.32	.53	.029	.025	.06	.12	.38	.04
2-5494	Acid-Arc	.38	.70	.48	.025	.025	1.93	.93	.35	.04
4-666	Single Induction	.39	.70	.37	.020	.012	1.70	1.34	.42	.06
4-771	Single Induction	.39	.62	.42	.020	.006	1.50	.96	.37	.05
1-4752	Basic-Arc	.42	..82	.47	.007	.006	1.60	1.12	.44	.04
4-815	Arc Induction	.37	.66	.44	.008	.008	1.48	1.08	.42	.04
4-816	Arc Induction	.38	.64	.47	.008	.008	1.50	1.04	.41	.04
4-830	Arc Induction	.39	.73	.45	.009	.006	1.49	1.00	.39	.04

*Arc-Induction melting consisted of melting the master alloy from 1-4752 in the induction furnace.

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*Single induction melting consisted of melting a virgin charge of Armco iron and ferroalloys.

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TABLE III

MECHANICAL PROPERTIES OF 4340 STEEL CASTINGS PRODUCED IN THIS INVESTIGATION

HEAT NUMBER	CASTING CONFIG-URATION	TEST SPECIMEN (location)	HEAT TREATMENT (final)	UTS (PSI)	Y.S. (1%) (PSI)	Y.S. (2%) (PSI)	Elong. %	R.A. %	CHARPY-V IMPACT-40° ft. lbs.
4-666	DTA-59827 (Solid-Arm)	Mid-wall	Aust. - 1640°F Q - 1350°F T - 850°F	203,000	188,000	191,500	10.0	27.5	-
4-666	DTA-59827 (Solid-Arm)	Mid-wall	Aust. - 1640°F Q - 1350°F T - 850°F T - 900°F	196,500	173,500	177,000	10.5	27.2	8.3
4-666	DTA-59827 (Solid-Arm)	Center	Aust. - 1640°F Q - 1350°F T - 850°F T - 900°F	207,000	-	est. 176,000	4.5	8.2	-
4-771	DTA-59827 (Solid-Arm)	Mid-wall	Aust. - 1650°F Q - 1650°F T - 900°F	198,000	184,000	184,500	8.5	19.5	7.5
1-4752	DTA-59827 (Solid-Arm)	Mid-wall	Aust. - 1650°F Q - 1650°F T - 900°F	202,000	175,000	178,000	10.0	27.5	10.0
1-4752	DTA-59827 (Solid-Arm)	Mid-wall	Aust. - 1650°F Q - 1650°F T - 900°F Cold Treat (-) 140°F T - 900°F	207,500	177,500	182,500	8.0	15.2	6.7*

* - Specimens not machined correctly.

Note: Impact values are the average of 3 specimens.

(15)

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TABLE III (continued)

HEAT NUMBER	CASTING CONFIG-URATION	TEST SPECIMEN (location)	HEAT TREATMENT (final)	UTS (PSI)	Y.S. (1%) (PSI)	Y.S. (2%) (PSI)	Elong. %	R.A. %	CHARPY-V IMPACT-40° ft. lbs.
1-4752	DTA-59831 (Hollow arm)	Mid-wall *	Aust. - 1650°F Q - 1650°F T - 900°F	203,500	-	est. 180,000	3.5	8.3	8.6
1-4752	DTA-59831 (Hollow arm)	Mid-wall	Aust. - 1650°F Q - 1650°F T - 900°F	187,500	175,000	181,000	Broke in	threads	-
4-815	Finned Test Cstg.	Fin	Aust. - 1650°F Q - 1650°F T - 900°F	207,000	178,500	182,500	9.5	20.2	11.3
4-816	Finned Test Cstg.	Fin	Aust. - 1650°F Q - 1650°F T - 900°F	206,500	177,000	180,500	9.3	20.2	11.8
4-830	Finned Test Cstg.	Fin	Aust. - 1650°F Q - 1650°F T - 900°F	205,000	179,000	181,500	9.0	21.6	12.6

* - Macro etched cross section showed area where Charpy specimens were removed to be relatively sound. Areas where tensile specimens were removed was not sound on micro scale.

NOTE: Impact values are the average of 3 specimens.

I. MACHINING TECHNIQUES

All castings submitted for field testing were machined by Eagle Tool and Machine Company, Springfield, Ohio. The information provided on machining techniques has been supplied by Eagle Tool and Machine.

MACHINE	OPER. NO.	OPERATION	TOOLING
	10	Inspect Raw Casting & Layout complete to insure proper stock allowances have been made.	
V.Boring Mill	20	Bore the 4.540+ .003 Dia. hole to 4.002-4.005. Face the 3-7/8 Dim. Backside to maintain 5-9/32 computed dimension.	DTA-59826-F-1
V.Boring Mill	30	Shift Fixture and Bore the 4.183 Dia. to 4.002-4.005 Face the 2-9/16 Dimension to size.	DTA-59826-F-1
V.Boring	40	Shift Fixture and Bore the 3.500 + .001 Dia. to 3.00 $\pm$ .010 Face the 4.000 Dim. to 4-1/8	DTA-59826-F-1
	50	Inspect 20-30-40	
H.Boring Mill	60	Face 3-7/8 Dim. Holding 1-13/32 Dim. Turn the 8.086 - .005 Dia. x 1/4 Deep.	DTA-59826-F-2
	70	Inspect 8.086 - .005 Locating Dia. and the 1-13/32 Step.	
H.Boring Mill	80	Face 4.00 Dimension to Size Turn the 7.532 - .005 x 7/16 Deep and 1/32 x 45° Chamfer Bore the 3.500 + .001 Diameter Drill (6) .297 Dia. x .219 Deep Holes.	DTA-59826-F-2 Std. Gilbert knee
H.Boring Mill	90	Bore the 4.002-4.005 to 4.540 + .003 Bore the 4.002-4.005 to 4.183 + .003 Drill (6) .281 Dia. x .250 Deep holes	DTA-59826-F-2

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I. MACHINING TECHNIQUES (Cont'd.)

MACHINE	OPER. NO.	OPERATION	TOOLING
V.Shaper	100	Machine 92 Serrations. Maintain the 4.614 + .006 Dia.	DTA-59826-F-3 DTA-59826-T-1 DTA-59826-G-1
		Note: In this operation use grinding fixture DTA-59826-F-4 to insure conformity of tools.	
	110	Inspect complete and record findings for record.	

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VI. MISCELLANEOUS

A. HOLLOW SUSPENSION ARM

Castings were also produced with a hollow arm connecting the hubs. These castings were produced by the methods outlined in the procedure section, except that a zircon sand core was used to produce the hollow section. It was found that this foundry practice did not promote the desired soundness on the micro scale. Mechanical properties of one casting (DTA-59831) produced by this method are listed in Table III. The modification of foundry practice required to produce a "sound" casting in this configuration was not attempted during this investigation.

B. CASTINGS FOR FIELD TESTING

Four castings were submitted for field testing. Processing data for these castings are supplied in Table IV. These castings were heat treated with finned test castings - mechanical properties of finned test castings listed in Table II.

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TABLE IV

PATTERN NUMBER	SERIAL NUMBER	HEAT NUMBER	WELDING	DISCONTINUITIES FOUND IN NONDESTRUCTIVE TESTING
DTA-59826	5	4-830	Figure 6	None
DTA-59826	13*	4-816	Figure 7	None
DTA-59826	15	1-4752	None	None
DTA-59827	10	4-815	Figure 8	None
DTA-59827	11	4-815	Figure 9	None

* NOT MACHINED

VII. SUGGESTIONS FOR FUTURE WORK

A. Determine the effect of heat treatment under reduced pressure as a method of improving mechanical properties of castings produced by controlled solidification.

B. Use high-purity charge materials, and determine their effect on the mechanical properties of castings produced by controlled solidification.

C. Development of foundry practice capable of producing sound hollow suspension arm castings.

D. Produce useful castings at higher strength levels.

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VIII. ACKNOWLEDGMENTS

The author is grateful for the valuable assistance given him by the personnel of the Bonney-Floyd Company in the preparation of this report.

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IX. BIBLIOGRAPHY

1. AHEARN, P.J., HOLMES, K.D., ZOTOS, J., "Mechanical Properties And Processing Techniques For High Strength Steel Castings", Report No. RPL 10/19, Watertown Arsenal, Rodman Laboratory, 1959.

2. BARONE, R.V., FLEMINGS, M.C., TAYLOR, H.F., URAM, S.Z., "Solidification of Steel Castings And Ingots", Modern Castings, Vol. 40, pp. 422-435 (1961).

3. FLEMINGS, M.C., TAYLOR, H.F., URAM, S.Z., "High Strength Cast Steel Structure and Microporosity Effect on Mechanical Properties", Modern Castings, Vol. 38, No. 1, pp. 61-74 (1960).

4. ZOTOS, J., "Optimum Operating Procedure for Basic Electric Steel Furnace for Desulphurization and Dephosphorization", Journal of Steel Castings Research, No. 8, May, 1957; pp. 12-16.

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Design information was used to develop manufacturing procedures which related each production operation to the function of cast high strength steel suspension arm. The individual operations, pattern making, rigging, molding, melting, riser removal, heat treatment, inspection and machining were then utilized in the production of suspension arm castings.

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